Survey of Red Sea Urchin Populations Off Campbell River, British Columbia, 2002

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SURVEY OF RED SEA URCHIN POPULATIONS OFF CAMPBELL RIVER, BRITISH COLUMBIA, 2002

by

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ABSTRACT

Atkins, M., Tzotzos, D., Hajas, W.C., and Campbell, A. 2006. Survey of red sea urchin populations off Campbell River, British Columbia, 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2753: iii + 25 p.

A survey of red sea urchin populations was conducted near Campbell River (Pacific Fisheries Management, PFM sub-areas 13-1, 13-2 and 14-13) during July/August, 2002. A total of 54 transects were surveyed by SCUBA divers, and 5246 red sea urchins were measured. In PFM sub-areas 13-1, 13-2 and 14-13, the density (number/m^2) of red sea urchins of all sizes was 1.72/m^2, 1.60/m^2 and 0.19/m^2, respectively, and for legal-sized red urchins (≥90 mm test diameter) the density was 0.90/m^2, 0.60/m^2 and 0.09/m^2, respectively. Estimated mean densities and biomass (g/m^2) were significantly higher for red sea urchins found inside (26 transects) compared to outside (28 transects) previously fished commercial bed areas; densities were also compared by depth. Overall, 18.1% of all red urchins measured were ≤50 mm test diameter whereas 44.9% were of legal size for the commercial fishery.

RÉSUMÉ

Atkins, M., Tzotzos, D., Hajas, W.C., and Campbell, A. 2006. Survey of red sea urchin populations off Campbell River, British Columbia, 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. 2753: iii + 25 p.

Un relevé des populations d'oursins rouges a été réalisé en juillet-août 2002 près de Campbell River (sous-secteurs 13-1, 13-2 et 14-13 de gestion des pêches du Pacifique). Au total, 54 transects ont été couverts par des plongeurs autonomes, qui ont mesuré 5246 oursins rouges. Dans les sous-secteurs 13-1, 13-2 et 14-13, la densité (nombre/m^2) des oursins rouges de toutes tailles était respectivement de 1,72/m^2, 1,60/m^2 et 0,19/m^2, et, pour les oursins de taille réglementaire (≥90 mm de diamètre du test, DT), la densité était respectivement de 0,90/m^2, 0,60/m^2 et 0,09/m^2. La densité moyenne estimée et la biomasse (g/m^2) étaient nettement plus élevées pour les oursins rouges observés à l'intérieur (26 transects) comparativement à l'extérieur (28 transects) de gisements auparavant exploités par la pêche commerciale; les densités ont aussi été comparées selon la profondeur. Dans l'ensemble, 18,1 % de tous les oursins rouges mesurés présentaient ≤50 mm DT, tandis que 44,9 % avaient la taille réglementaire pour la pêche commerciale.

INTRODUCTION

Red sea urchin (*Strongylocentrotus franciscanus*) distribution along the Pacific Coast of North America ranges from the southern tip of Baja California to Alaska (Kato and Schroeter 1985). Red sea urchins are found throughout shallow rocky subtidal habitats of British Columbia (Bernard 1977; Campbell and Harbo 1991). Sea urchins are commercially harvested for their gonads (roe), which are sold mainly in Japan. Coastal First Nations communities harvest sea urchins as part of their traditional food, social and ceremonial fisheries. The commercial red sea urchin fishery began in British Columbia (BC) in the early 1970's and the total landed value for the 2003-2004 season was $7.7 million (Juanita Rogers, pers. comm.), making the harvest of red sea urchins a valuable shellfish fishery in BC.

The commercial red sea urchin fishery history and management were described in Campbell and Harbo (1991), and Campbell et al. (1999a). Currently, several approaches are used in the management of the red sea urchin fishery, including: a minimum commercial harvest size of 90 mm test diameter (TD); area licensing; individual vessel quotas; area quotas; and limited licence entry. Quota calculations are based on estimates of urchin density from field surveys, and estimates of urchin bed areas. Density estimates are therefore essential to the assessment and management of the sea urchin fishery.

Early red sea urchin population surveys were conducted during the 1970's and 1980's by Breen et al. (1976, 1978), Adkins et al. (1981) and Sloan et al. (1987). Since 1993, red sea urchin population surveys have been conducted as a joint effort between the Pacific Urchin Harvesters Association (PUHA), First Nations, and Fisheries and Oceans Canada (DFO) (Jamieson et al. 1998a-d; Bureau et al. 2000a-d; Tzotzos et al. 2003a-d, 2006; Atkins et al. 2006a-g).

Fishery managers request that red sea urchin surveys be conducted to update density and biomass estimates to help determine quotas. The Campbell River area [parts of Pacific Fishery Management (PFM) Area 13, sub-areas 1 and 2, and Area 14, sub-area 13] (Figure 1), was selected for survey through discussion between PUHA and DFO. The objective of this paper was to present detailed survey results and to estimate red sea urchin density and biomass for PFM sub-areas 13-1, 13-2, and 14-13.

METHODS

SURVEY AREA AND TRANSECT LAYOUT

Survey efforts were concentrated in PFM sub-areas 13-1, 13-2, and 14-13 (Figure 1). Transect locations were selected and plotted on a marine chart prior to the survey to avoid bias in the field.

Transects were systematically placed along the shoreline with a random starting point. The ArcView GIS system was used to measure the shoreline length (SL) of the survey area, including islands. The position of the first transect was determined randomly, and subsequent transects were then spaced evenly along the shoreline. Areas of unsuitable red sea urchin habitat (eg. sand and mud substrates) were excluded from the survey area. Since variation in urchin density was unlikely to match the spacing of the transects, the systematic sample was treated as a random sample of transects (Jamieson and Schwarz 1998).

SURVEY LOGISTICS

The survey was conducted between July 28 and August 5, 2002. The PUHA provided the "McLaughlin Bay", a commercial red sea urchin fishing vessel, with a crew of four divers, one of which was a biologist, and the others were commercial red sea urchin harvesters.

DIVE SURVEY METHODS

In the field, location of transects were determined from geographical references on the shoreline and GPS. Exposure to wave action/current was recorded, for each transect, as one of nine codes: 0 = extreme shelter, 1 = minimal sea movement, 2 = well sheltered, 3 = occasional current, 4 = moderate exposure, 5 = strong tidal flow, 6 = high tide surge only, 7 = ground swell normal, 8 = high exposure. Leadline transects were laid perpendicular to shore from the boat, with a float attached to the deep end of each transect. Transects were laid out from shallow water to a depth of 15m (not corrected for tide), so transect length was dependent on the slope of the substrate and tide height. A two-diver team surveyed each transect from deep to shallow, one diver measured urchins while the other recorded data. A one meter squared (1 m^2) quadrat was placed on the bottom beside the transect and the test diameter (TD) of each red urchin present was measured, with callipers, to the nearest millimeter. If urchins could not be measured because they were inaccessible or broken/lost they were still counted, therefore the count of urchins in a quadrat may be higher than the number measured. The depth, substrate type, types of algae (and percent cover), shell length of abalone (*Haliotis kamtschatkana*), and TD of green (*S. droebachiensis*) and purple (*S. purpuratus*) sea urchins present in each quadrat were also recorded. The quadrat was then moved 2 m forward along the transect and the process was repeated, so that every second meter of the transect was surveyed. In cases where no urchins were found at the deep end of transects, observations of depth, substrate and algae were recorded only every 20 m to minimize dive time. In such cases, skipped quadrats were assigned zero values for urchin counts before data were analysed. Once urchins were encountered, sampling was conducted every 2 m until the intertidal zone or the surface was reached.

DATA ANALYSIS

Habitat

Depth Categories

Gauge depths recorded by divers were corrected to depth below Chart Datum by subtracting tide height from the observed depths. Tide heights from the closest tide station at Campbell River were used to correct depths. The depth (m) for each quadrat was assigned to one of seven depth ranges: 1= <0.0m; 2= 0.0 - <2.5m; 3= 2.5 - <5.0m; 4= 5.0 - <7.5m; 5= 7.5 - <10.0m; 6= 10.0 -<12.5m; and 7= ≥12.5m.

Substrate

The divers recorded the dominant substrates (up to three) within each quadrat using one of nine generic codes: 1=smooth bedrock; 2=bedrock with crevices; 3=boulders, >30cm; 4=cobble, between 7.5cm and 30cm; 5=gravel, between 2cm and 7.5cm; 6=pea gravel, between 0.25-2cm; 7=sand; 8=shell; and 9=mud. For the analysis, the nine substrate codes were grouped into three main dominant categories: 1=rock (codes 1-5); 2=sand/shell (codes 6-8); and 3=mud (code 9). Each quadrat was assigned a dominant substrate code in order to determine the average percent of each dominant substrate.

Algae

Algal species were assigned to one of four categories based on growth characteristics: canopy (taller than 2m), understorey (30cm to 2m), turf (<30cm), and encrusting. The percent cover of algae in each category, for each quadrat, was calculated as the sum of the individual species' percent cover. Mean percent cover, by growth category, for each depth category was then calculated by averaging the quadrat percent covers over the depth category.

Estimation of Density and Biomass

Density and biomass estimates were calculated from transects that were located inside commercially harvested red sea urchin beds, for transects located outside of the harvested beds, and for all transects combined. Commercially harvested beds were defined as areas where commercial harvesting occurred between 1997 and 2000; therefore, areas defined as outside beds may have had fishing events prior to 1997 and/or after 2000. The process involved in defining the commercially harvested urchin beds was described by Campbell et al. (2001).

Density and biomass were estimated for red urchins in three size groups: a) all sizes, b) small urchins <50 mm TD, and c) urchins of legal size for the commercial fishery (≥90 mm TD). Estimates of mean density and biomass were calculated using the equations below.

Density estimates (d_{ts}) in number of red sea urchins per meter squared for each transect (t) and size group (s) were calculated as:

$$d_{ts} = \frac{N_{ct}}{a_t} * \frac{N_{mts}}{N_{mt}} \quad (1)$$

where N_{ct} is the total number of red urchins counted on transect t, N_{mts} is the number of red urchins measured in size group s on transect t, N_{mt} is the total number of red urchins measured on transect t, and a_t is the surface area of all quadrats surveyed on the transect t. Here a_t is equal to the number of all quadrats surveyed on the transect since each quadrat had a surface area of 1 m^2.

Overall mean density ($\bar{d}_s$) for a PFM sub-area, for urchins of size group s, was estimated as a weighted mean of transect densities:

$$\bar{d}_s = \frac{\sum_t (d_{ts} * L_t)}{\sum_t L_t} \quad (2)$$

where L_t is the length of transect t (Campbell et al. 1999b).

The standard error ($s_{\bar{d}}$) of estimated mean density was calculated as:

$$s_{\bar{d}} = \sqrt{1 - \frac{n}{T}} * \sqrt{\frac{\sum_t (d_{ts} * L_t - \bar{d}_s * L_t)^2}{n * (n-1) * \bar{L}^2}} \quad (3)$$

where n is the number of transects surveyed, T is the total possible number of transects that can be sampled in a surveyed PFM sub-area and mean transect length ($\bar{L}$) was calculated as:

$$\bar{L} = \frac{\sum_t L_t}{n} \quad \text{(Campbell et al. 1999b)} \quad (4)$$

The expression $\sqrt{(1-(n/T))}$ was approximately equal to 1 since n was much smaller than T.

To calculate biomass, the weight of each red urchin measured was calculated using the relationship between urchin weight (W) in grams and test diameter (TD) in millimetres (Campbell et al. 1999b, 2000).

$$W = 0.0012659 * TD^{2.7068} \quad n= 167, r^2=0.960 \quad (5)$$

Biomass density (b_{ts} in grams per meter squared) of urchins of size group s, on a transect t, was estimated using a simplified form of the formula used in previous papers (Campbell et al. 2000). The formula was modified by Campbell et al. (1999b) to simplify computations:

$$b_{ts} = \frac{N_{ct}}{N_{mt}} * \frac{\sum W_{ts}}{a_t} \quad (6)$$

where N_{ct} is the total number of red urchins counted on transect t, N_{mt} is the total number of red urchins measured on transect t, ΣW_{ts} is the sum of the weights of red urchins measured in size group s on transect t and a_t is the surface area of quadrats surveyed on the transect t.

Overall estimated mean biomass ($\bar{b}_s$) per surface area (grams per meter squared) was calculated as a weighted mean of transect biomass:

$$\bar{b}_s = \frac{\sum_t (b_{ts} * L_t)}{\sum_t L_t} \qquad \text{(Campbell et al. 1999b)} \qquad (7)$$

The standard error of estimated mean biomass was calculated using the same formula used for standard errors of density, but d_{ts} and $\bar{d}_s$ were substituted for b_{ts} and $\bar{b}_s$, respectively. The biomass estimate, for each PFM sub-area surveyed, was converted into quota recommendations for management purposes by Campbell et al. (2001).

A Kruskal Wallace Analysis (Systat 10) was used to compare red urchin densities between inside and outside of commercial beds overall and for each PFM sub-area.

Density and biomass estimates were also generated by depth.

Recruitment

Estimates of recruitment (R_T) of red sea urchin populations in BC have generally been expressed as a percentage of the total number of red sea urchins measured that were ≤50 mm TD (Adkins et al. 1981; Breen et al. 1976, 1978; Jamieson et al. 1998b, 1998c, 1998d; Sloan et al. 1987). For comparison purposes, the same method was used here. Recruitment was also calculated as a percentage of the total number of sub-legal red sea urchins (<90 mm TD) that were ≤50 mm TD (R_S). This method may provide a less biased measure of recruitment in areas where a commercial fishery has taken place, since the numbers of sea urchins ≥90 mm TD may be reduced due to the harvest (Tegner and Dayton 1981).

RESULTS

SURVEY LOGISTICS

In total, 54 transects were surveyed during nine dive days (Table 1, Figure 1). A total of 5246 red sea urchins were measured in 2914 quadrats on the 54 transects. Total transect length surveyed was 9194m, for an average transect length of 170m. Twenty-six (26) transects were located in the commercial red sea urchin beds recorded from 1997 to 2000.

SUBSTRATE AND HABITAT

All transects surveyed were in areas of high exposure. Of the 2914 quadrats sampled, 68% had rock, 28% had gravel/sand/shell, and 5% had mud as the primary substrate. Of the 5246 red sea urchins counted, 86% were observed between 0.0 m and 7.5 m.

When looking at algal abundance at depths of <10.0 m, understorey algae were consistently encountered at all depths, turf was more abundant in shallow water and encrusting algae abundance increase with depth. Canopy species of algae were scarce, and were not found below 10 m.

SIZE FREQUENCY DISTRIBUTIONS

The mean size of all red sea urchins measured was 81.2 mm TD (Table 3, Fig. 2). The smallest and largest urchins measured were 5 mm and 168 mm TD, respectively. By PFM sub-areas, 13-1, 13-2 and 14-13 had a mean size of 80.7 mm TD, 80.9 mm TD and 86.6 mm TD, respectively. Overall, the mean size of red urchins inside and outside of commercial bed areas was 80.4 mm and 90.6 mm TD, respectively.

The overall percentage of legal-sized urchins (≥90 mm TD) was 44.9%, whereas the percentage of urchins ≤50 mm TD (R_T) was 18.1%. Of the sublegal urchins, the percentage that was ≤50 mm TD (R_S) was 32.8%. By PFM sub-area, the percentage of legal-sized red sea urchins in sub-areas 13-1, 13-2 and 14-13 was 52.4%, 37.7% and 46.4%, respectively, the percentage ≤50 mm TD (R_T) was 22.3%, 15.1% and 10.7%, respectively, and the percentage of sublegal red urchins ≤50mm TD (R_S) was 46.9%, 24.2% and 20.0%, respectively (Table 3).

Forty four percent (44%) of the red sea urchins sampled inside commercial bed areas (n=4830) were of legal size, as were 54% of the red urchins sampled outside bed areas (n=416); percentages by PFM sub-area are also displayed in Table 3.

DENSITY AND BIOMASS ESTIMATES

For all transects combined, the estimated mean density and biomass for red sea urchins of all sizes was 1.13/m^2 and 273.91 g/m^2 respectively, and 0.51/m^2 and 203.58 g/m^2 for legal-sized urchins (Table 4). Significant differences in density between in and out of bed areas were observed for red urchins of all sizes, for legal-sized urchins, and for urchins ≤50mm TD (Table 5).

Overall (PFM sub-areas combined), for transects lying on commercial red sea urchin beds, the estimated mean density of red urchins of all sizes was 2.13/m^2, and was 0.94/m^2 for legal-sized urchins. For transects lying outside of commercial bed areas, the estimated mean density was 0.18/m^2 for red urchins of all sizes, and 0.09/m^2 for legal-sized urchins. Inside bed areas, the estimated mean biomass of red urchins of

all sizes was 503.90 g/m^2, and was 371.75 g/m^2 for legal-sized urchins; outside bed areas the estimated mean biomass was 53.42 g/m^2 and 42.37 g/m^2 respectively (Table 4).

The mean density and biomass estimates of red sea urchins by depth are displayed in Tables 6 and 7, respectively, although no statistical testing was performed. The highest density and biomass estimates were found in the 7.5 – 10m depth category.

DISCUSSION

The mean TD of red sea urchins found within commercially harvested bed areas was smaller than those red urchins found outside of commercial bed areas. There are a number of possible hypotheses for this, such as harvesting in bed areas resulting in the removal of larger urchins, low recruitment outside of bed areas causing a shift in the size frequency, or simply an artefact of low sample size.

Recruitment was defined as the percentage of the total red sea urchin population that was ≤50 mm TD (R_T). Numerous factors could influence recruitment in any given area including physical and oceanographic influences, predation on larvae and juveniles, and interactions between juveniles and adults (Kalvass 1992; Sloan et al. 1987). The percentage of recruits (R_T) on commercial beds in Campbell River was 18.9% and the density recruits ≤50 mm TD was 0.40/m^2. A recent survey in Queen Charlotte Strait (2004) saw a higher observed percentage of recruits (26.3%) and density ≤50 mm TD (0.79/m^2) (Atkins et al. 2006g); and another recent survey closer to Campbell River off Robson Bight (2001) had a much lower percentage of recruits (5.4%) and density ≤50 mm TD (0.07/m^2) (Atkins et al. 2006e). A survey in the Deserters group in 2000 observed a lower percentage of recruits (4.8%) however saw a recruit density much higher (2.12/m^2) (Tzotzos et al. 2003a). Overall, near Campbell River, densities within commercial bed areas were significantly higher than densities observed outside of bed areas, for all size classes (all sizes, ≥90 mm TD, and ≤50 mm TD).

The density of recruits (≤50 mm TD) outside commercial bed areas was very low; however, sample size should be increased to confirm the accuracy of this observation. In sub-areas 13-1 and 13-2 no red urchins ≤50 mm TD were found outside commercial beds, and along 19 transects outside beds in sub-area 14-13, the recruit density was 0.02/m^2. This indicates that commercial harvesters are returning to the areas at which the physical and/or biological conditions are well suited for red urchin population growth and sustainability.

When compared with other recent surveys, the overall mean density (2.13/m^2) of red sea urchins (all sizes) in commercial beds off Campbell River was higher than near Robson Bight where the density within harvested bed areas was 1.24/m^2 (Atkins et al.

2006e), similar to the Deserters Group (2.12/m^2) (Tzotzos et al. 2003a), and lower than Queen Charlotte Strait (2.83/m^2) (Atkins et al. 2006g).

Total mean density increased with depth to 10m and remained high to the survey limit of 12.5m, below which transects were not normally surveyed. Algal food in this survey was more abundant in the shallower water, which suggested some other factors were possibly forcing the red sea urchins into deeper water. The substrates became rockier with increased depth in the area surveyed, which favoured the deeper distribution of red sea urchins. Urchins require hard substrate to hang onto, especially when exposed to high tidal currents, which are common in the Campbell River area. The summertime warming of the surface water near Campbell River may also drive the red urchins deeper, as urchins have a narrow tolerance to temperature changes.

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Table 1. Summary of transects surveyed during the July 28 – August 5, 2002 red sea urchin (RSU) population survey near Campbell River. Density in number per meter squared and biomass in grams per meter squared. PFM = Pacific Fishery Management. Depths have been corrected to chart datum. Check marks (✓) indicate transect lying within a known commercial RSU harvest area.

Transect	PFM Sub-area	Latitude	Longitude	Depth (m)		Time		Total Time (minutes)	Transect Length(m)	Number Quadrats	Number RSU Counted	RSU Density	RSU Biomass	In Bed
				Minimum	Maximum	Start	End							
1	13-1	50 00.430	125 08.690	0.43	7.13	13:51	14:00	9	161	9	0	0.00	0.00	
2	13-1	50 00.350	125 08.860	1.34	7.13	14:12	14:21	9	121	7	0	0.00	0.00	
3	13-1	50 00.250	125 09.010	1.04	6.52	14:30	14:42	12	141	8	0	0.00	0.00	
4	13-1	50 00.150	125 09.150	1.68	6.83	14:54	15:13	19	119	60	19	0.32	114.15	
5	13-1	50 00.040	125 09.380	0.15	6.86	15:42	15:53	11	141	8	0	0.00	0.00	
6	13-1	49 59.872	125 09.550	2.62	7.77	16:07	16:33	26	161	81	44	0.54	268.27	✓
7	13-1	49 59.680	125 09.720	0.21	7.35	14:00	14:58	58	281	141	157	1.11	294.25	✓
8	13-1	49 59.550	125 10.000	-0.37	7.19	13:25	14:25	60	281	141	191	1.35	420.44	✓
9	13-1	49 59.320	125 09.970	5.76	8.75	09:46	13:03	197	201	101	171	1.69	407.80	✓
10	13-1	49 59.330	125 10.610	0.94	10.27	15:55	17:35	100	169	85	514	6.05	1274.94	✓
11	13-1	49 59.480	125 11.010	0.09	9.39	09:03	09:59	56	141	71	305	4.30	836.12	✓
12	13-1	49 59.570	125 11.320	0.40	7.99	10:14	11:45	91	121	61	455	7.46	1959.63	✓
13	13-1	49 59.660	125 11.560	0.67	7.22	12:17	13:27	70	101	51	366	7.18	1599.51	✓
14	13-1	49 59.750	125 11.688	2.26	8.96	13:45	13:53	8	61	4	0	0.00	0.00	✓
15	13-2	49 59.670	125 13.460	0.27	8.50	09:15	09:40	25	141	71	57	0.80	180.54	✓
16	13-2	49 59.520	125 13.400	0.91	8.84	09:55	10:06	11	121	7	0	0.00	0.00	✓
17	13-2	49 59.390	125 13.310	1.07	7.65	10:18	11:06	48	161	81	224	2.77	391.67	✓
18	13-2	49 59.230	125 13.230	1.89	7.96	11:28	13:00	92	181	91	362	3.98	542.37	✓
19	13-2	49 59.050	125 13.120	1.98	9.88	09:07	09:42	35	141	71	186	2.62	729.56	✓
20	13-2	49 58.910	125 13.130	-0.58	6.71	16:50	17:25	35	181	91	89	0.98	343.74	✓
21	13-2	49 58.770	125 13.010	2.59	8.08	10:21	11:14	53	141	71	165	2.32	480.06	✓
22	13-2	49 58.600	125 12.790	0.06	7.01	09:48	10:05	17	181	91	29	0.32	111.83	✓
23	13-2	49 58.400	125 12.600	-1.01	4.75	09:12	09:28	16	181	10	0	0.00	0.00	
24	13-2	49 58.378	125 12.570	1.43	6.58	14:19	14:34	15	181	10	0	0.00	0.00	
25	13-2	49 58.320	125 12.320	-0.67	6.00	15:00	16:00	60	81	41	293	7.15	1527.20	✓
26	13-2	49 58.040	125 12.013	2.47	8.38	09:23	11:20	117	179	90	495	5.50	1160.01	✓
27	13-2	49 57.840	125 12.000	2.19	7.13	11:50	13:10	80	201	101	328	3.25	1009.42	✓
28	13-2	49 57.700	125 12.050	3.02	5.43	11:42	12:24	42	341	171	48	0.28	94.07	✓
29	13-2	49 57.520	125 11.991	3.35	8.20	13:00	13:36	36	191	96	54	0.56	187.04	✓
30	13-2	49 57.370	125 11.870	2.47	7.22	13:51	14:17	26	221	111	33	0.30	95.63	✓
31	13-2	49 57.220	125 11.769	2.29	6.28	14:42	14:54	12	141	71	1	0.01	3.17	✓
32	13-2	49 57.160	125 11.600	2.41	5.85	15:12	16:09	57	201	101	186	1.84	505.26	✓

Continued next page

Table 1. continued

Transect	PFM Sub-area	Latitude	Longitude	Depth (m)		Time		Total Time (minutes)	Transect Length(m)	Number Quadrats	Number RSU Counted	RSU Density	RSU Biomass	In Bed
				Minimum	Maximum	Start	End							
33	13-1	49 56.980	125 11.090	1.92	7.44	14:20	14:50	30	179	90	77	0.86	249.52	✓
34	13-1	49 56.860	125 11.070	2.26	8.90	13:15	13:55	40	181	91	80	0.88	361.79	
35	13-1	49 56.720	125 10.900	1.80	9.39	12:40	12:50	10	181	91	0	0.00	0.00	
36	14-13	49 56.500	125 10.610	3.17	6.64	11:45	12:20	35	69	35	113	3.23	734.46	
37	14-13	49 56.080	125 10.370	6.77	9.27	10:20	10:44	24	421	22	0	0.00	0.00	
39	14-13	49 55.840	125 10.560	3.57	9.36	11:15	11:55	40	321	161	166	1.03	314.61	
40	14-13	49 55.580	125 10.530	2.19	8.50	12:20	12:38	18	221	12	0	0.00	0.00	
41	14-13	49 55.410	125 10.640	2.13	6.64	12:08	12:22	14	181	10	0	0.00	0.00	
42	14-13	49 55.230	125 10.700	2.04	5.27	12:36	13:04	28	181	91	38	0.42	110.67	
43	14-13	49 55.050	125 10.630	4.02	6.43	13:45	14:00	15	181	10	0	0.00	0.00	
44	14-13	49 54.920	125 10.460	4.66	6.80	14:17	14:33	16	181	10	0	0.00	0.00	
45	14-13	49 54.750	125 10.294	4.94	7.10	14:50	15:04	14	181	10	0	0.00	0.00	
46	14-13	49 54.600	125 10.060	4.30	6.16	15:19	15:31	12	181	10	0	0.00	0.00	
47	14-13	49 54.431	125 09.950	2.10	5.12	14:00	14:18	18	181	10	0	0.00	0.00	
48	14-13	49 54.290	125 09.710	1.22	5.18	14:35	14:50	15	181	10	0	0.00	0.00	
49	14-13	49 54.116	125 09.380	-1.22	4.88	15:10	15:25	15	161	9	0	0.00	0.00	
50	14-13	49 54.088	125 08.926	2.04	8.23	13:12	13:23	11	121	7	0	0.00	0.00	
51	14-13	49 53.910	125 08.480	2.74	8.29	13:37	13:42	5	41	3	0	0.00	0.00	
53	14-13	49 53.680	125 07.805	1.65	6.28	13:55	14:01	6	41	3	0	0.00	0.00	
55	14-13	49 53.360	125 07.100	1.49	5.49	14:14	14:20	6	61	4	0	0.00	0.00	
57	14-13	49 53.090	125 06.690	2.07	6.83	14:38	15:00	22	221	12	0	0.00	0.00	
59	14-13	49 52.570	125 06.490	1.28	6.22	15:17	15:27	10	161	9	0	0.00	0.00	

Table 2. Mean number of red sea urchins (RSU), substrate category, and percent cover of algae for each depth category surveyed during the 2002 survey conducted near Campbell River. Depths have been corrected to chart datum. Substrate categories: 1=rock; 2=sand/shell; 3=mud. Canopy = tall, shading, surface-reaching algae. Understorey = 30cm to 2m in height. Turf = 5cm to 30cm in height. Encrusting = species forming a thin, crustose layer on rocks.

Depth	Number of RSU		Number	Mean Substrate	Mean Percent Cover by Algae			
Range (m)	Total	Mean per Quadrat	Of Quadrats	Category	Canopy	Understorey	Turf	Encrusting
PFM sub-area 13-1								
<0.0 m	0	0	13	1.00	0	0	90	0
0.0 - <2.5 m	38	0.2	145	1.34	1.3	23.2	40.1	6.4
2.5 - <5.0 m	490	1.7	292	1.60	0.7	16.3	13.8	14.5
5.0 - <7.5 m	1419	2.8	512	1.31	3.6	18.8	8.3	37.4
7.5 - <10.0 m	430	3.1	137	1.44	3.0	36.6	6.1	35.9
10.0 - <12.5 m	2	2.0	1	1.00	0	0	0	80.0
PFM sub-area 13-2								
<0.0 m	0	0	13	1.38	0	28.8	56.9	3.8
0.0 - <2.5 m	141	0.9	165	1.25	8.6	33.4	40.7	9.1
2.5 - <5.0 m	1066	1.9	566	1.21	5.5	31.3	19.9	17.7
5.0 - <7.5 m	985	1.9	528	1.31	6.4	23.7	8.2	17.0
7.5 - <10.0 m	312	3.2	99	1.15	0	17.5	5.6	21.2
10.0 - <12.5 m	0	0	0	0	0	0	0	0
PFM sub-area 14-13								
<0.0 m	0	0	4	2.00	0	74.3	0	0
0.0 - <2.5 m	0	0	21	2.29	0	47.9	9.3	0.2
2.5 - <5.0 m	224	1.4	164	1.92	4.1	53.7	5.0	8.6
5.0 - <7.5 m	93	0.5	198	1.46	1.1	48.5	2.7	12.9
7.5 - <10.0 m	0	0	51	1.21	0	68.0	4.3	7.5
10.0 - <12.5 m	0	0	0	0	0	0	0	0
Sub-areas 13-1, 13-2, and 14-13 combined								
<0.0 m	0	0	30	1.15	0	22.4	63.7	1.7
0.0 - <2.5 m	225	0.7	336	1.35	4.9	29.9	38.5	7.4
2.5 - <5.0 m	1780	1.7	1022	1.43	3.9	30.6	15.8	15.3
5.0 - <7.5 m	2497	2.0	1238	1.34	4.4	25.7	7.3	24.8
7.5 - <10.0 m	742	2.6	287	1.30	1.4	35.6	5.6	25.8
10.0 - <12.5 m	2	2.0	1	1.00	0	0	0	80.0
≥12.5 m	None Surveyed							

Table 3. Number and mean size of red sea urchins measured and percent of urchins ≤50mm TD and ≥90mm TD for each Pacific Fishery Management (PFM) sub-area surveyed during the 2002 survey conducted near Campbell River. R_T = percent of all red urchins that were ≤50mm TD. R_S = percent of sublegal urchins that were ≤50mm TD.

PFM Sub-Area	Transects Used	Test Diameter (mm)			Numbers Measured			% Total Measured		% Sublegal
		Mean	Minimum	Maximum	Total	≤50 mm TD	≥90 mm TD	≤50 mm (R_T)	≥90 mm	≤50 mm (R_S)
13-1	Within Beds	79.7	8	164	2280	529	1171	23.2	51.4	47.7
	Outside Beds	103.5	22	154	99	2	76	2.0	76.8	8.7
	All	80.7	8	164	2379	531	1247	22.3	52.4	46.9
13-2	Within Beds	80.9	10	168	2550	384	961	15.1	37.7	24.2
	Outside Beds	0	0	0	0	0	0	0.0	0.0	0.0
	All	80.9	10	168	2550	384	961	15.1	37.7	24.2
14-13	Within Beds	0	0	0	0	0	0	0.0	0.0	0.0
	Outside Beds	86.6	5	142	317	34	147	10.7	46.4	20.0
	All	86.6	5	142	317	34	147	10.7	46.4	20.0
Survey Total	Within Beds	80.4	8	168	4830	913	2132	18.9	44.1	33.8
	Outside Beds	90.6	5	154	416	36	223	8.7	53.6	18.7
	All	81.2	5	168	5246	949	2355	18.1	44.9	32.8

Table 4. Mean density and biomass estimates of red sea urchins by size (test diameter, TD), within and outside of commercial beds, by Pacific Fishery Management sub-area, for the 2002 survey conducted near Campbell River. Estimates are for transects within red sea urchin beds recorded between 1997 and 2000, for transects outside the beds, and for all transects combined. Values in brackets are ± S.E..

PFM Sub-areas	Transects Surveyed	Number Of Transects	Sum of Transect Lengths (m)	Mean Density (no./m^2) for TD			Mean Biomass (g/m^2) for TD		
				≤50 mm	≥90 mm	All Sizes	≤50 mm	≥90 mm	All Sizes
13-1	Within Beds	10	1696	0.62 (0.20)	1.37 (0.34)	2.67 (0.77)	9.10 (2.73)	536.68 (128.34)	650.16 (168.12)
	Outside Beds	7	1045	0.00	0.14 (0.12)	0.19 (0.15)	0.07 (0.07)	68.86 (54.45)	75.66 (59.83)
	All	17	2741	0.38 (0.14)	0.90 (0.24)	1.72 (0.53)	5.65 (1.89)	358.32 (93.21)	431.13 (117.89)
13-2	Within Beds	16	2804	0.27 (0.11)	0.68 (0.16)	1.81 (0.46)	5.66 (2.15)	271.98 (60.77)	415.44 (98.93)
	Outside Beds	2	362	0.00	0.00	0.00	0.00	0.00	0.00
	All	18	3166	0.24 (0.10)	0.60 (0.15)	1.60 (0.43)	5.01 (1.93)	240.89 (57.00)	367.93 (91.97)
14-13	Within Beds			none surveyed					
	Outside Beds	19	3287	0.02 (0.02)	0.09 (0.06)	0.19 (0.12)	0.38 (0.30)	38.61 (24.64)	52.24 (32.78)
	All	19	3287	0.02 (0.02)	0.09 (0.06)	0.19 (0.12)	0.38 (0.30)	38.61 (24.64)	52.24 (32.78)
Survey Total	Within Beds	26	4500	0.40 (0.11)	0.94 (0.17)	2.13 (0.40)	6.95 (1.68)	371.75 (64.13)	503.90 (88.26)
	Outside Beds	28	4694	0.02 (0.01)	0.09 (0.05)	0.18 (0.09)	0.28 (0.21)	42.37 (20.90)	53.42 (26.28)
	All	54	9194	0.21 (0.06)	0.51 (0.10)	1.13 (0.23)	3.55 (0.92)	203.58 (39.15)	273.91 (53.01)

Table 5. Kruskal-Wallace test results for comparing mean densities of red sea urchins by size groups between inside and outside commercial bed areas by PFM sub-area for the 2002 population survey near Campbell River.

PFM Sub-area	P-values		
	≤50 mm	≥90 mm	All Sizes
13-1	**0.003**	**0.004**	**0.004**
13-2	**0.111**	**0.048**	**0.035**
14-13	n/a	n/a	n/a
Sub-areas combined	**0.000**	**0.000**	**0.000**

Table 6. Mean density estimates of red sea urchins by depth range for all urchins surveyed inside commercial beds, outside commercial beds, and total urchins surveyed, during the 2002 survey conducted near Campbell River. Values in brackets are ± S.E..

Depth Range (m)	Transect Count	Mean Density (number/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-area 13-1										
<0.0 m	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0 – <2.5 m	15	0.07 (0.06)	0.00	0.04 (0.03)	0.71 (0.68)	0.42 (0.40)	0.58 (0.41)	1.58 (1.54)	0.52 (0.50)	1.11 (0.87)
2.5 – <5.0 m	16	0.33 (0.19)	0.00	0.20 (0.11)	0.86 (0.49)	0.16 (0.14)	0.57 (0.29)	1.82 (1.02)	0.20 (0.18)	1.15 (0.59)
5.0 – <7.5 m	17	0.79 (0.27)	0.01 (0.01)	0.49 (0.18)	1.93 (0.56)	0.27 (0.20)	1.30 (0.40)	3.54 (1.11)	0.35 (0.26)	2.32 (0.75)
7.5 – <10.0 m	8	1.80 (0.81)	0.00	1.26 (0.65)	2.60 (1.03)	0.00	1.83 (0.86)	5.98 (2.79)	0.00	4.20 (2.20)
10.0 – <12.5 m	1	0.61	0.00	0.61	0.90	0.00	0.90	2.00	0.00	2.00
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PFM sub-area 13-2										
<0.0 m	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0 – <2.5 m	15	0.04 (0.03)	0.00	0.03 (0.03)	0.40 (0.29)	0.00	0.34 (0.25)	0.89 (0.56)	0.00	0.76 (0.49)
2.5 – <5.0 m	18	0.26 (0.10)	0.00	0.23 (0.09)	0.77 (0.20)	0.00	0.68 (0.18)	2.06 (0.63)	0.00	1.82 (0.57)
5.0 – <7.5 m	17	0.30 (0.13)	0.00	0.29 (0.13)	0.80 (0.25)	0.00	0.75 (0.24)	1.90 (0.51)	0.00	1.78 (0.49)
7.5 – <10.0 m	8	0.57 (0.29)	0.00	0.57 (0.29)	0.75 (0.26)	0.00	0.75 (0.26)	2.48 (0.85)	0.00	2.48 (0.85)
10.0 – <12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PFM sub-area 14-13										
<0.0 m	1		0.00	0.00		0.00	0.00		0.00	0.00
0.0 – <2.5 m	11		0.00	0.00		0.00	0.00		0.00	0.00
2.5 – <5.0 m	18	n/a	0.05 (0.05)	0.05 (0.05)	n/a	0.29 (0.21)	0.29 (0.21)	n/a	0.60 (0.42)	0.60 (0.42)
5.0 – <7.5 m	18		0.03 (0.03)	0.03 (0.03)		0.15 (0.12)	0.15 (0.12)		0.31 (0.25)	0.31 (0.25)
7.5 – <10.0 m	5		0.00	0.00		0.00	0.00		0.00	0.00
10.0 – <12.5 m	0		0.00	0.00		0.00	0.00		0.00	0.00
≥12.5 m	0		0.00	0.00		0.00	0.00		0.00	0.00

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Table 6. continued.

Depth Range (m)	Transect Count	Mean Density (number/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-areas combined										
<0.0 m	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.0 – <2.5 m	41	0.05 (0.03)	0.00	0.03 (0.02)	0.52 (0.31)	0.14 (0.14)	0.34 (0.18)	1.15 (0.67)	0.17 (0.17)	0.69 (0.36)
2.5 – <5.0 m	52	0.28 (0.09)	0.04 (0.03)	0.16 (0.05)	0.80 (0.21)	0.23 (0.15)	0.52 (0.13)	1.98 (0.53)	0.45 (0.28)	1.21 (0.31)
5.0 – <7.5 m	52	0.49 (0.14)	0.03 (0.02)	0.26 (0.08)	1.23 (0.28)	0.17 (0.10)	0.71 (0.17)	2.51 (0.53)	0.30 (0.19)	1.43 (0.32)
7.5 – <10.0 m	21	1.07 (0.39)	0.00	0.63 (0.27)	1.50 (0.50)	0.00	0.88 (0.34)	3.89 (1.27)	0.00	2.28 (0.89)
10.0 – <12.5 m	1	0.61	0.00	0.61	0.90	0.00	0.90	2.00	0.00	2.00
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Biomass estimates of red sea urchins by depth range for all urchins surveyed inside commercial beds, outside commercial beds, and total urchins surveyed, during the 2002 survey conducted near Campbell River. Values in brackets are ± S.E.

Depth Range (m)	Transect Count	Mean Biomass (g/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-area 13-1										
<0.0 m	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0– <2.5 m	15	2.10 (2.00)	0.00	1.18 (1.12)	323.82 (312.87)	194.62 (188.04)	267.07 (187.40)	460.36 (449.55)	213.84 (206.60)	352.08 (259.82)
2.5 – <5.0 m	16	5.51 (3.18)	0.02 (0.02)	3.25 (1.85)	333.25 (189.99)	73.48 (66.99)	226.37 (111.45)	436.81 (245.63)	80.74 (73.60)	290.31 (143.25)
5.0 – <7.5 m	17	11.88 (3.94)	0.16 (0.17)	7.41 (2.70)	753.07 (217.50)	126.78 (95.75)	514.30 (152.78)	889.79 (264.12)	139.32 (105.21)	603.68 (182.32)
7.5 – <10.0 m	8	23.42 (10.45)	0.00	16.45 (8.38)	998.33 (385.39)	0.00	701.13 (323.12)	1258.41 (536.21)	0.00	883.79 (434.70)
10.0 – <12.5 m	1	7.38	0.00	7.38	338.44	0.00	338.44	421.67	0.00	421.67
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PFM sub-area 13-2										
<0.0 m	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0 – <2.5 m	15	0.86 (0.65)	0.00	0.74 (0.56)	159.65 (117.69)	0.00	136.47 (101.28)	237.28 (161.86)	0.00	202.83 (139.42)
2.5 – <5.0 m	18	5.74 (2.19)	0.00	5.08 (1.97)	309.28 (75.33)	0.00	273.92 (70.02)	481.71 (245.63)	0.00	426.63 (124.38)
5.0 – <7.5 m	17	5.96 (2.45)	0.00	5.60 (2.32)	327.81 (108.38)	0.00	307.93 (103.35)	463.78 (136.46)	0.00	435.66 (130.68)
7.5 – <10.0 m	8	10.75 (4.90)	0.00	10.75 (4.90)	284.00 (100.64)	0.00	284.00 (100.64)	473.73 (154.71)	0.00	473.73 (154.71)
10.0 – <12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Table 7. continued.

Depth Range (m)	Transect Count	Mean Biomass (g/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-area 14-13										
<0.0 m	1		0.00	0.00		0.00	0.00		0.00	0.00
1.0– <2.5 m	11		0.00	0.00		0.00	0.00		0.00	0.00
2.5 – <5.0 m	18	n/a	0.98 (0.85)	0.98 (0.85)	n/a	124.54 (92.05)	124.54 (92.05)	n/a	166.58 (121.04)	166.58 (121.04)
5.0 – <7.5 m	18		0.58 (0.55)	0.58 (0.55)		60.79 (47.43)	60.79 (47.43)		83.32 (65.81)	83.32 (65.81)
7.5 – <10.0 m	5		0.00	0.00		0.00	0.00		0.00	0.00
10.0 – <12.5 m	0		0.00	0.00		0.00	0.00		0.00	0.00
≥12.5 m	0		0.00	0.00		0.00	0.00		0.00	0.00
PFM sub-areas combined										
<0.0 m	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0 – <2.5 m	41	1.34 (0.85)	0.00	0.71 (0.45)	222.85 (136.50)	65.23 (64.82)	148.20 (78.13)	323.17 (193.82)	71.67 (71.22)	204.05 (107.84)
2.5 – <5.0 m	52	5.66 (1.77)	0.66 (0.57)	3.17 (0.96)	317.62 (79.74)	101.50 (64.02)	209.89 (50.94)	466.09 (120.57)	131.47 (83.61)	299.29 (73.51)
5.0 – <7.5 m	52	8.19 (2.16)	0.45 (0.40)	4.39 (1.22)	488.08 (111.16)	74.10 (40.81)	284.55 (66.36)	624.34 (133.05)	93.30 (53.06)	363.26 (80.79)
7.5 – <10.0 m	21	15.88 (5.20)	0.00	9.31 (3.64)	573.12 (188.64)	0.00	336.19 (131.05)	791.32 (249.10)	0.00	464.19 (175.63)
10.0 – <12.5 m	1	7.38	0.00	7.38	338.44	0.00	338.44	421.67	0.00	421.67
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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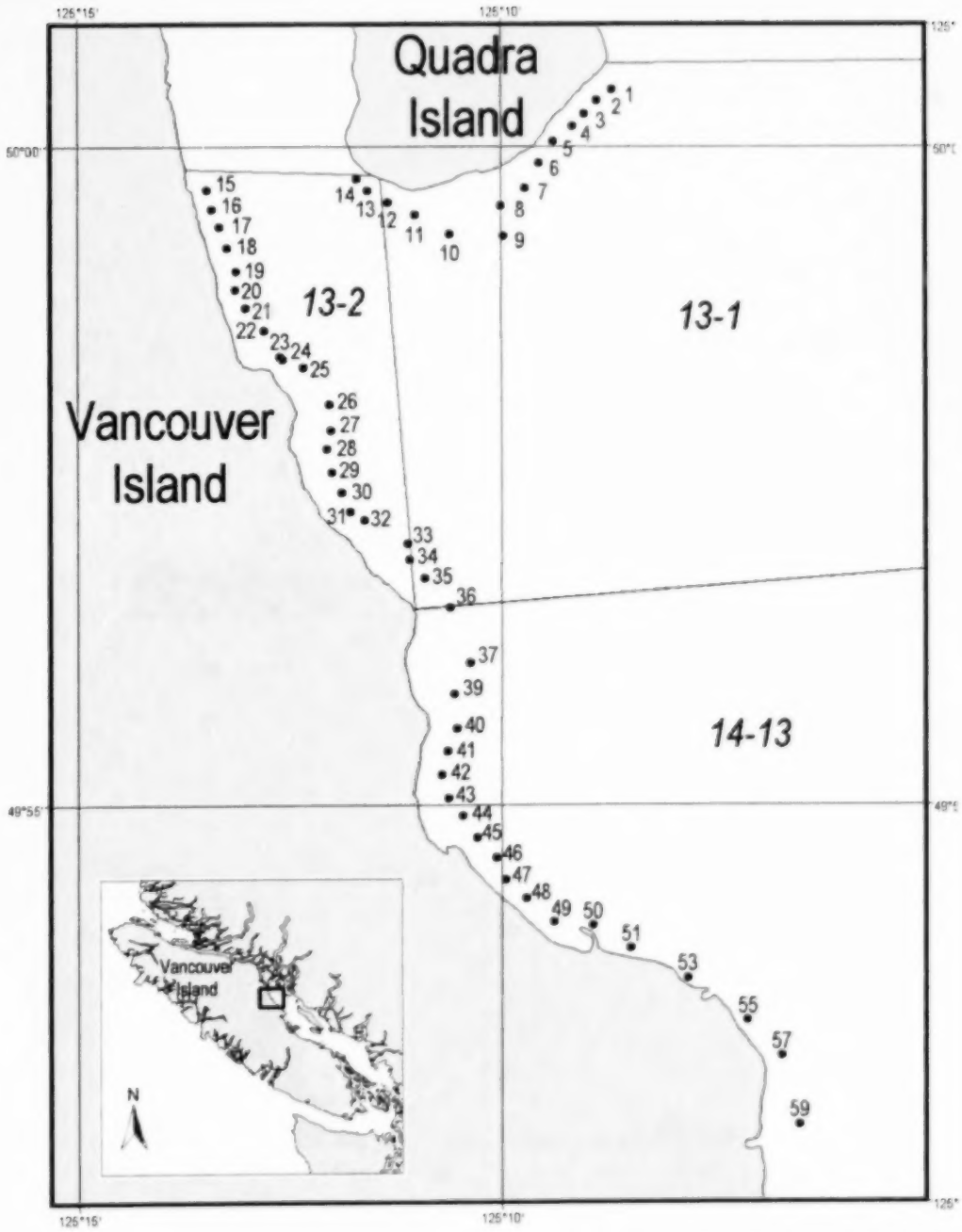

Figure 1. Map of survey area and transect locations for the red sea urchin population survey conducted near Campbell River, 2002. Hyphenated numbers indicate Pacific Fishery Management sub-areas, and smaller numbers identify transect locations. Inset figure denotes survey location.

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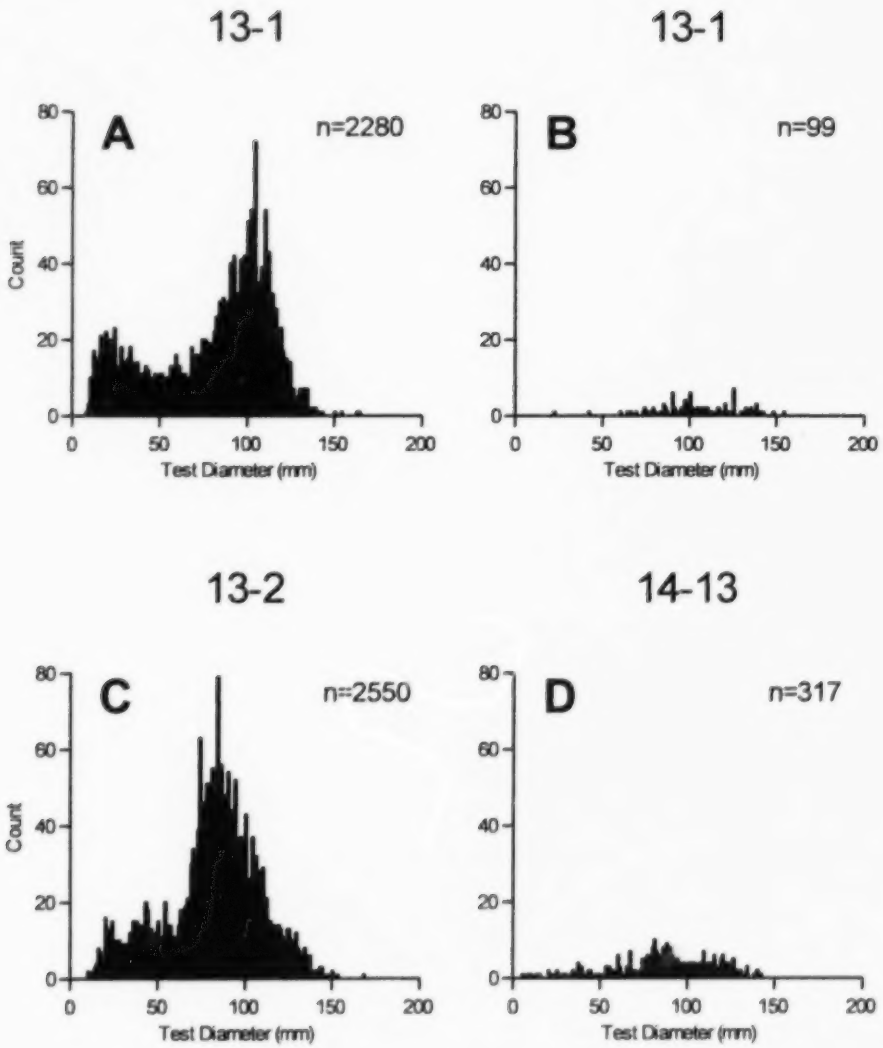

Figure 2. Size frequency distribution of red sea urchins measured along transects inside (A,C) and outside (B,D) of commercial bed areas during the 2002 survey near Campbell River. Pacific Fishery Management sub-areas are indicated above the figures. n= number of red sea urchins measured for test diameter.